

SOFIA Science Instrument System Specification

SOF-AR-SPE-SE01-2028

Date: 18 April 2011

Revision: -



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SOFIA Science Instrument System Specification


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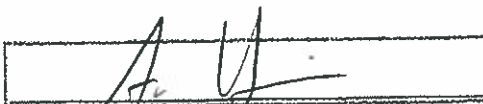
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VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

SOFIA Science Instrument System Specification

Revision History

Vertical bars in the margin of the page denote revisions to the document from the previous issue.

REV	DATE	DESCRIPTION	APPROVAL
-	4/18/2011	PMB approved baseline release per PRG-CCR-063	PMB

Paragraph Identification (parid)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parents - SE01-003	V&V Method (multiple selectable)	V&V Activity	V&V Review & Approval Authority
1	Introduction, Overview and Scope				NVR		
1.1	Introduction The SOFIA Science Instrument (SI) System Specification is one of three level 2 system specifications in the SOFIA specification tree, along with the Airborne System Specification and the SOFIA Science and Mission Operations (SSMO) Specification (see SOF-DF-SPE-SE01-068, <i>SOFIA Specification/Product Tree</i>). The Airborne System Specification contains the requirements on the airborne observatory, including the aircraft, Telescope Assembly (TA), and Mission Controls and Communication System (MCCS) but does not contain requirements on the Science Instruments. The Science and Mission Operations Specification contains the requirements on the Data Cycle System (DCS), Mission Operations, and ground support for Science Instruments. This Science Instrument System Specification contains the generic science instrument requirements for SOFIA science instruments mounted on the telescope assembly. This specification does not contain the science instrument science and technical performance requirements, as those are specific to the instrument type and scientific investigations proposed.				NVR		
	For U.S. instruments, the science and technical performance requirements will be contained in an instrument Science and Technical Performance Requirements Document. The performance requirements will be described in the instrument proposals and will be a factor in instrument selection. Prior to the science instrument System Requirements Review (SRR) the instrument teams will release a Science and Technical Performance Requirements Document to the SOFIA Program for acceptance.				NVR		
	The parent document of this specification is SOF-DF-SPE-SE01-003, <i>SOFIA System Specification</i> .				NVR		
	These terms are used in this document: Shall – Mandatory, Verifiable requirement for SI Developer implementation Should – Goal or recommendation for SI Developer implementation (Non-Verifiable) Will – Statement of fact, or signifies intent (e.g., NASA will verify, analyze, etc.)				NVR		
	The definitions, abbreviations, and acronyms used in this specification are as defined within SOF-DF-PD-PD-2009, <i>SOFIA Lexicon</i> . The first instance of each abbreviation and acronym in this specification is given as a parenthetical after the complete spelling of the words.				NVR		

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1.2	<p>Overview</p> <p>The requirements in this document ensure the science instrument can properly interface with the aircraft systems (i.e. MCCS) and the telescope assembly, as well as meeting the ground safety requirements and airworthiness requirements. This specification includes requirements for compliance with a number of Interface Control Documents (ICD). This specification along with those ICDs and the instrument specific Science and Technical Performance Requirements are the complete set of requirements for Science Instruments.</p>				NVR		
	<p>The ground safety requirements are the rules necessary for operating in a NASA leased facility in the state of California, and represent a combination of state and federal regulations as well as NASA policies.</p> <p>To ensure the safety of the personnel onboard the aircraft and of the SOFIA observatory, all equipment onboard the aircraft needs to be deemed airworthy before it can be flown. This document contains the airworthiness instrument requirements to be verified prior to the issuance of an approval letter by the Science Instrument Airworthiness Team (SIAT).</p> <p>The airworthiness approval and certification process for science instruments is described in SCI-AR-HBK-OP03-2000, <i>SOFIA Science Instrument Developers' Handbook</i>.</p>				NVR		
	<p>The following are topics that pertain to the airworthiness of a science instrument:</p> <ul style="list-style-type: none"> • Anything that can cause injury to personnel; • Anything that can cause a fire; • Commands by one system to others that result in hazardous conditions; • Systems that monitor, providing warning of, or prevent hazardous conditions; • Anything that affects the aircraft pressure boundaries; • Foreign Object Damage and equipment security; • Pressure systems; • Cryogenics; • Toxic substances; and • Radiation, both ionizing and non-ionizing 				NVR		
1.3	<p>Scope</p> <p>This document applies to SOFIA Science Instruments. It includes instruments produced via contract, subcontract, or grant. It includes instruments acquired by NASA or its international partners, except that requirements within agreements between NASA and its international partner will take precedence over this document.</p> <p>For first generation science instruments, the requirements in this document will be tailored case-by-case through mutual agreement of the SI Developer and NASA.</p>				NVR		

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2	<p>Applicable Compliance and Reference Documents</p> <p>The latest revisions of the following ICDs, specifications and standards form a part of this requirement to the extent specified herein.</p> <p>Those documents that are cited as sources of mandatory requirements appear in the Compliance Documents section. These are applicable to SI design and development activities performed in-house or outsourced by the SI Developer.</p> <p>Those documents that are cited as sources of recommended guidelines or for reference only appear in the Reference Documents section.</p>				NVR		
2.1	<p>Precedence</p> <p>In the event of a conflict between the text of this document and the referenced documents cited herein, the text of this document takes precedence. Nothing in this document, however, supercedes the contractual requirements unless a specific exemption has been obtained and approved. As appropriate, reference is made to other project documentation for use as guidance in developing the content of this document and as such forms a basis for requirements to the extent specified herein.</p>				NVR		
2.2	Compliance Documents				NVR		
2.2.1	Interface Control Documents (ICDs)				NVR		
	SOF-DA-ICD-SE03-002 (GLOBAL_09), <i>Science Instrument Envelope</i>	3.11.1			NVR		
	SOF-DA-ICD-SE03-037 (TA_SI_02), <i>Telescope Assembly / Science Instrument Mounting Interface</i>	3.11.2; TA_SI_02 Figure 4-1 has known inaccuracies and is in revision to correct the locations of the 4 holes with threaded inserts for jack screws [Ref.: Correction to TA_SI_02 Figure 4-1 (09/13-04): Front View of IMF (INF)].			NVR		
	SOF-DA-ICD-SE03-2015 (SI_AS_01), <i>PI Equipment to PI Rack to Aircraft System</i>	3.11.3			NVR		
	SOF-DA-ICD-SE03-036 (TA_SI_01), <i>Cable Load Alleviator Device / Science Instrument Cable Interface</i>	3.11.4			NVR		
	SOF-DA-ICD-SE03-051 (TA_SI_05), <i>SI Equipment Rack / TA Counterweight Interface</i>	3.11.5			NVR		
	SCI-AR-ICD-SE03-2027 (SI_CWR_01), <i>SI Equipment to Counterweight Rack ICD</i>	3.11.6			NVR		
	SOF-DA-ICD-SE03-052 (MCCS_SI_04), <i>MCCS to Science Instrument Software Interface (SCL) (Functional)</i>	3.1.2			NVR		
	SCI-US-ICD-SE03-2023 (DCS_SI_01), <i>Data Cycle System (DCS) of the SOFIA Project ICD</i>	3.11.7			NVR		
	SOF-AR-ICD-SE03-2029 (MCCS_SI_05), <i>PI Patch Panel to PI Equipment Rack(s)</i>	3.11.8			NVR		
	SOF-DA-ICD-SE03-038 (TA_SI_04), <i>TA Chopper Processor / Principal Investigator Computer Direct Analog Interface</i>	3.11.9			NVR		
	SCI-AR-ICD-SE03-2017 (SIC_SSMO_01), <i>SI Handling Cart to SSMO Facility Interface</i>	3.11.10			NVR		
	SOF-AR-ICD-SE03-205 (SIC_AS_01), <i>SI Handling Cart to Aircraft System ICD</i>	3.11.11			NVR		
	SCI-AR-ICD-SE03-2020 (SSMO_SI_02), <i>TA Alignment Simulator (TAAS) to Science Instrument ICD</i>	3.11.12			NVR		
	SOF-DA-ICD-SE03-2022 (VPS_SI_01), <i>SI to Aircraft Vacuum Pump</i>	3.11.13			NVR		

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2.2.2	SOFIA Specifications and other Compliance Documents				NVR		
	SCI-US-SPE-SW01-2028, <i>Data Processing (Pipeline) Software Requirements Document (SRD) for SOFIA Science Instruments</i>	3.1.5, 3.2.1			NVR		
2.2.3	Standards				NVR		
	NASA-STD-8719.9, <i>Standard for Lifting Devices and Equipment</i> , Sections 6, 7, 8, 10, and 13	3.5.2.5			NVR		
	NASA-STD-8719.17, <i>NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PVS)</i>	3.5.3.5			NVR		
2.3	Reference Documents				NVR		
2.3.1	SOFIA Specifications and other Reference Documents				NVR		
	SCI-AR-HBK-OP03-2000, <i>SOFIA Science Instrument Developers' Handbook</i>	1.2, 3.10.1.1, 3.10.1.2, 3.5.6.1, 3.5.6.2, 3.11			NVR		
	SOF-DF-SPE-SE01-068, <i>SOFIA Specification/Product Tree</i>	1.1			NVR		
	SOF-DF-SPE-SE01-003, <i>SOFIA System Specification</i>	1.1, 3.9.1, SE01-003, <i>SOFIA System Specification</i> , is the parent document for SE01-2028. SE01-003 Appendix A Figure 1 & Figure 2 (SI In-Flight Access) referenced in 3.9.1.			NVR		
	SOF-DF-PD-PD-2009, <i>SOFIA Lexicon</i>	1.1			NVR		
	SCI-AR-ICD-SE03-2034 (SI_KOSMA Translator_01), <i>KOSMA Translator to SI ICD</i>	3.1.2, Compliance to this ICD is a derived requirement that supports SI compliance with MCCS_SI_04 for instruments that leverage existing code developed for interface with the KOSMA Observatory.			NVR		
	SCI-US-PLA-PM17-2010, <i>Data Processing Plan for SOFIA Science Instruments</i>	3.1.5, 3.2.1			NVR		
	SOF-DF-ICD-SE03-048 (TA_MCCS_P), <i>Telescope Assembly / Mission Controls and Communications System (MCCS) Physical Interface</i>	3.5.4.2, References Section 3.3.12 for guidance re: grounding, bonding, signal shielding and power circuit returns			NVR		
	APP-DF-PRO-OP02-2043, <i>Procedure for Crossing the TA Barrier during Flight</i>	3.9.1, Provided as reference for investigator in-flight access to SI equipment on TA / CWR.			NVR		
2.3.2	Standards				NVR		
	ASME Section VIII, Division 2, Alternative Rules for Construction of Pressure Vessels; Parts 4, 5, 7 and 8	3.5.3.3.1, 3.5.3.3.2, Reference this ASME code for guidance re: hydrostatic test procedures, NDE inspection, combination of stresses and analytical methods for pressure vessels.			NVR		
	Compressed Gas Association (CGA) E-4, Standard for Gas Pressure Regulators, Appendix A	3.5.3.4, References Appendix A for calculations of flow through a failed regulator based on published Cv			NVR		

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3	Requirements				NVR		
3.1	Functional				NVR		
3.1.1	Science Instruments shall be tolerant of unannounced removal or reduction of input power with no permanent functional or performance degradation.	<p>Notes:</p> <ol style="list-style-type: none"> Such power interruptions can have varying characteristics and therefore may need to be addressed by different design implementations. For example: <ol style="list-style-type: none"> Relatively short transients, typically less than 1 second in duration (and often more likely to be on the order of milliseconds), such as those associated with the routine transfer of power from ground to aircraft power (and vice-versa) which must not damage the SI; Relatively long power outages (i.e., "blackouts") of up to several hours in duration, which may require an orderly shutdown to "safe" the SI For Science Instruments that utilize the Vacuum Pumping System (VPS) to achieve detector temperatures lower than that of liquid Helium at 1 atmosphere, developers should also consider the likelihood that a power interruption may impact the nominal operation of this system. <p>Rationale:</p> <p>Unannounced power interruptions are anticipated and must be tolerated by Science Instruments. While SI equipment that is considered sensitive to power fluctuations should use the onboard UPS, proper function of this UPS should not be assumed for the purposes of this requirement, which is intended to ensure that the SI will not suffer <i>permanent functional or performance degradation</i>, even in the event of a UPS failure.</p>			Analysis & Demonstration		SSP SE&I
3.1.2	SOFIA Science Instruments shall send commands, request and receive housekeeping data, store data, and transfer stored science data during flight to the MCCS for archiving in accordance with the Mission Controls and Communications System (MCCS) interface requirements in accordance with SOF-DA-ICD-SE03-052 (MCCS_SI_04), <i>MCCS to Science Instrument Software Interface (SCL) (Functional)</i> .	<p>Notes:</p> <p>Certain SI software developments may wish to leverage existing code developed for interfacing with the Kölner Observatorium für Submillimeter Astronomie (KOSMA); such developments would then have a derived requirement to additionally comply with SCI-AR-ICD-SE03-2034 (SI_KOSMA Translator_01), <i>KOSMA Translator to SI ICD</i>, for compliance with this MCCS_SI_04 interface requirement.</p> <p>MCCS provides command, control and data transfer functionality between SIs and SOFIA subsystems including the TA, DCS, SOFIA Command Language (SCL), etc. MCCS_SI_04 is the ICD that defines the functional requirements for this SI interface.</p> <p>Rationale:</p> <p>The requirement that SIs transfer stored science data during the flight supports the Level 1 requirements that data is to be transferred from the platform to the ground-based data archive after each flight to ensure that no essential data is lost (ref.: SE01-003 ¶ 3.1.29), and to provide quick-look access to raw science and housekeeping data from the flight to science investigators within 3 hours after each flight (ref.: SE01-003 ¶ 3.2.14).</p>		3.1.29 3.2.14	Demonstration		SSP SE&I
3.1.3	SOFIA Science Instruments shall time stamp data transferred to the MCCS.	<p>Note:</p> <p>UTC reference time from the SOFIA Network Time Protocol (NTP) Server may be obtained via broadcast on the MCCS LAN and/or the coax IRIG-B distribution subsystem, or as ASCII text in response to SOFIA Command Language (SCL) commands [ref.: SOF-DA-ICD-SE03-052 (MCCS_SI_04), MCCS to Science Instrument Software Interface (SCL) (Functional), Section 4.4].</p> <p>Rationale:</p> <p>Data from dissimilar instruments must be compared for post-flight analysis. Most experiments require a modest level of synchronization compatible with the performance of the standard network time protocol.</p>		3.1.31	Demonstration		SSP SE&I

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3.1.4	SOFIA Science Instrument data shall be tagged with position of the observatory.	Note: The GPS position reference source may be the SOFIA facility GPS provided via the MCCA, or may be internal to the Science Instrument. Rationale: The SI requires access to a time and position reference to time tag data with accuracies and precisions needed for occultations and transit observations. The SI also requires a common time and position reference, such as GPS, that allows synchronization between measurements taken by independent ground-based instruments and airborne measurements taken by SOFIA.		3.1.43	Inspection		SSP SE&I
3.1.5	SOFIA Science Instrument data processing software shall comply with the requirements for pipeline data processing of Science Instrument data as defined in SCI-US-SPE-SW01-2028, <i>Data Processing (Pipeline) Software Requirements Document (SRD) for SOFIA Science Instruments</i> .	Notes: SCI-US-SPE-SW01-2028, <i>Data Processing (Pipeline) Software Requirements Document (SRD) for SOFIA Science Instruments</i> , together with SCI-US-ICD-SE03-2023 (DCS_SI_01), <i>Data Cycle System (DCS) of the SOFIA Project ICD</i> levied by para. 3.11.7 of this specification, define the SI requirements for interface with the DCS and provision of data analysis pipeline software. Further information re: data post-processing and data products may be found in SCI-US-PLA-PM17-2010, <i>Data Processing Plan for SOFIA Science Instruments</i> . Rationale: Data from all SOFIA observations must be calibrated and stored in the DCS archive, in order to provide a permanent record of the observation, enable guest investigators to access their data during their (nominal 1 year) period of exclusive access, and to allow future use by other investigators. For all SOFIA SIs, a data analysis pipeline must be developed and delivered to the SOFIA Science and Mission Operations - SOFIA Science Center (SSMO - SSC). During nominal operations, the SSMO - SSC will run the data analysis pipeline after each flight, perform calibrations, archive both raw and reduced data, and maintain appropriate access rights.		3.1.40 3.2.9	Demonstration	SI team will coordinate w/ assigned SOFIA Instrument Scientist(s) and the SMOC during development of selected SIs, including arranging for pipeline installation and training for pipeline software operation. During commissioning flights, the pipeline must be demonstrated. Acceptance of a facility instrument will depend upon successful demonstration of pipeline validity and operability.	SSP SE&I

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3.2	Performance				NVR		
3.2.1	SOFIA Science Instrument astronomical data shall be flux calibratable to within 20% RMS.	<p>Notes: Each SI will develop a Calibration Plan in collaboration with NASA.</p> <p>SCI-US-SPE-SW01-2028, <i>Data Processing (Pipeline) Software Requirements Document (SRD) for SOFIA Science Instruments</i> , presents requirements for the Data Analysis Pipeline architecture which supports compliance with quantitative calibration / performance requirements (i.e., the raw data from the SI need not comply with this requirement). Further information re: data post-processing and data products may be found in SCI-US-PLA-PM17-2010, <i>Data Processing Plan for SOFIA Science Instruments</i> .</p> <p>Rationale: Uncalibrated data is difficult to interpret and may be of little scientific value. SOFIA uses accepted flux standards of the astronomical community.</p>		3.2.9	Demonstration & Analysis		SSP SE&I
3.2.2	SOFIA Facility Class Science Instruments (FSIs) shall provide real-time estimates of cumulative signal-to-noise.	Supports real-time, in-flight decisions about the data acquisition and observing strategy.		3.1.3 3.2.8	Demonstration & Analysis		SSP SE&I
3.2.3	SOFIA Science Instruments shall provide a measurement of the alignment of the SI entrance pupil to the TA exit pupil to within an accuracy as flowed down from the applicable SI-specific throughput performance requirement.	Poorly aligned instruments do not couple effectively to the telescope optics and may suffer from an increased telescope background as a result of this misalignment. This requirement is related to the requirement for efficient observations and the need to achieve some level of successful science hours.		3.1.3 3.2.8	Demonstration or Test	Depends on specifics of SI design. Some instruments have fine opto-mechanical collimation adjustment capabilities that will allow them to meet this alignment spec. while mounted to the SOFIA TA IMS, while others may need to rely on the Telescope Assembly Alignment Simulator (TAAS) GSE, currently in development for use in the Preflight Integration Facility (PIF).	SSP SE&I

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3.5	Safety				NVR		
3.5.1	Hardware Containment and Foreign Object Debris / Damage (FOD) Control				NVR		
3.5.1.1	Screws, bolts, nuts, or other fasteners that are external to the Science Instrument flight hardware and TA INF, or are used to retain externally mounted components, shall use self-retaining / self-locking features.	<p>Notes:</p> <p>The following self-locking features are preferred, and will satisfy this requirement with no need for further review by the SIAT:</p> <ul style="list-style-type: none">• Threaded inserts (i.e., Helicoils) with locking features• Locking nuts or nutplates• Lock washers• Castellated nuts with cotter keys• Lead-sealed safety wire (consult with the SIAT for assistance with the proper application of safety wire) <p>In situations where the use of a preferred self-retaining or self-locking feature is deemed impractical (e.g., where frequent assembly / disassembly is needed), alternative fastener retention or locking implementations (e.g., loctite, staking) and/or periodic pre- and/or post-flight inspection methods (e.g., use of torque stripes or tamper-proof seals) may be approved by the SIAT on a case-by-case basis.</p> <p>For components that will be routinely accessed on the SOFIA aircraft (e.g., cryogen fill ports on SI cryostats, access hatches, keyboard and/or monitor tray locking pins, etc.), use of captive fasteners that do not require tools is strongly recommended (e.g., cotter keys tethered with lanyards).</p> <p>The use of COTS equipment for SI subsystems is anticipated. While COTS equipment is not exempt from this requirement, in cases where it is deemed impractical to meet this requirement, the SI developer must clearly identify this to the SIAT early in the design and airworthiness certification review process for assessment of risk and airworthy mitigations.</p> <p>Rationale:</p> <p>Science Instrument Airworthiness Team (SIAT) requirement to ensure that such fasteners will not loosen in the vibration environment, leading to unretained / uncontained hardware (i.e., FOD).</p>		3.5.5	Inspection		SIAT

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3.5.2	Structures				NVR		
3.5.2.1	The structure of SOFIA Science Instrument flight hardware shall be designed to maintain positive Margins of Safety (MS) for all handling, ground, airborne and emergency landing load conditions.	<p>Notes:</p> <p>The Ultimate Load Factors defined in Table 3.5-1, <i>Ultimate Load Factors</i> for structural calculations, envelope the Load Factors for ground (taxi), airborne and emergency landing inertial loads, and are to be used for structural calculations.</p> <p>For certain directions, the referenced table defines different Load Factors depending on whether the SI flight hardware is physically mounted to: 1. the Telescope Assembly (TA) Instrument Mounting Flange (IMF) or Counterweight Rack (CWR); or 2. the aircraft cabin / airframe via one of the PI Racks. The applicable Load Factors are to be used for each SI structure, based on the mounting location.</p> <p>The load conditions defined in Table 3.5-1 are prescribed in terms of ultimate loads, therefore a Safety Factor need not be applied in the analysis to show positive Margins of Safety, per Code of Federal Regulations Title 14, Chapter 1, Part 25 (FAR Part 25) Subpart C (Structure) § 25.303, <i>Factor of Safety</i>.</p> <p>For internal, mechanically-induced structural loads (i.e., not inertially-induced loads derived from Table 3.5-1), the design / verification must take into account the applicable Factor of Safety (FS) defined in Table 3.5-2, <i>Factor of Safety</i>, applied to the limit load.</p> <p>Rationale:</p> <p>Science Instrument Airworthiness Team (SIAT) requirement to ensure the structural integrity of SI flight hardware during emergency landing conditions.</p>	Table 3.5-1 Table 3.5-2	3.5.5	Analysis or Analysis & Test	<p>Calculate inertial loads based on mass and applicable Load Factors as defined in Table 3.5-1, and analyze stresses based on calculated loads applied to components' CGs to show that all critical structures have a positive Margin of Safety (MS).</p> <p>For mechanically induced (non-inertial) load conditions, use the applicable Factor of Safety (FS) as defined in Table 3.5-2 based on the material of the primary structure and the V&V Methodology.</p> <p>Analysis to include mass budget breakdown, CG analyses, load path definition, free body diagram and reaction force / moment calculations, overturning moment calculations, MS calculations.</p>	SIAT

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3.5.2.2	SI stands and carts to be used at a NASA facility shall be designed to maintain positive Margins of Safety (MS), with a minimum Safety Factor of 2 against deformation or yielding, and a minimum Safety Factor of 3 against collapsing, buckling, exceeding the ultimate load, or failing to support the design load in the vertical/downward direction.	<p>Notes: These minimum Safety Factors assume the use of ductile materials.</p> <p>The analysis must take into account all operational scenarios, including those in which the Science Instrument is not being supported by the GSE stand or cart.</p> <p>Rationale: Ensure the structural integrity of SI GSE stands and carts to be used aboard the SOFIA aircraft as well as ground-based laboratories, for the safety of personnel and to protect observatory, SI and laboratory assets.</p> <p>This is a recommended requirement for GSE support structures from NASA-STD-5005C, <i>Standard for the Design and Fabrication of Ground Support Equipment</i> (section 5.1.2).</p>			Analysis		SSP SE&I
3.5.2.3	SI stands and carts to be used at a NASA facility shall be proof load tested to 125% of the anticipated maximum design load in the vertical/downward direction.	<p>Note: For stands and carts that include integral jacks for lifting or leveling applications, this requirement is applicable for the full length of travel.</p> <p>Rationale: Ensure the structural integrity of SI GSE stands and carts to be used aboard the SOFIA aircraft as well as ground-based laboratories, for the safety of personnel and to protect observatory, SI and laboratory assets.</p> <p>This is a requirement for structural GSE from NASA-STD-5005C, <i>Standard for the Design and Fabrication of Ground Support Equipment</i> (section 4.6.2.1).</p> <p>NASA-STD-8719.9, <i>Standard for Lifting Devices and Equipment</i> (section 13.3.1) specifies a proof load test of 120% of rated load (it cites and appears to be a simplified composite of the static and dynamic proof load test conditions of ASME B30.1 section 1-1.4.14.2). We have opted to increase this to 125% of rated capacity to harmonize and merge the requirement with that from NASA-STD-5005C for non-lifting devices.</p>			Test & Inspection	A visual inspection shall be performed after the proof test to confirm no signs of yielding, deformation or other discrepancies (e.g., cracked welds, paint or other surface treatment, surface crazing, loose or missing fasteners, etc.). Test records shall be maintained and available for NASA review.	SSP SE&I
3.5.2.4	SI installation carts shall be designed to maintain positive Margins of Safety (MS) while sustaining the forward or rear impact of any one wheel of the cart with a 2 inch high curb.	<p>Notes: Analysis should assume the cart is fully loaded and is brought to rest from a velocity of 2 ft/s (0.6 m/s) in 0.1 s.</p> <p>No Safety Factor is neecessary for analysis of this off-nominal condition.</p> <p>Rationale: This requirement ensures the GSE cart (including the wheel/cart interface, structural braces and gussets, etc.) is sufficiently strong to withstand inadvertent impact with a curb or other low obstacle while the loaded cart is being pushed.</p> <p>The 0.6 m/s (~ 1.3 miles/hour) is believed to be a reasonable “speed limit” for a heavy SI cart being carefully and manually propelled by scientists or technicians in a laboratory setting, and falls within the range established by ISO 3691-5 <i>Industrial trucks - Safety requirements and verification</i> - Part 5: <i>Pedestrian-propelled trucks</i> (Annex A2.3), which calculates rolling forces for a manually propelled truck based on a speed of 0.5 m/s (+/- 20%).</p> <p>The 2 inch curb height is representative of typical obstacles that may be encountered at the DAOF. 0.1 s is a reasonable impact time per MIL-HDBK-1791, <i>Designing for Internal Aerial Delivery in Fixed Wing Aircraft</i> (section 4.2.3.2).</p>			Analysis		SSP SE&I

Paragraph Identification (parid)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parents - SE01-003	V&V Method (multiple selectable)	V&V Activity	V&V Review & Approval Authority
3.5.2.5	Lifting hardware GSE (e.g. hoists, slings, rigging, chains, spreader bars, etc.) provided by an SI developer for use at a NASA facility shall be designed and tested in accordance with the requirements of NASA-STD-8719.9, <i>Standard for Lifting Devices and Equipment</i> , Sections 6, 7, 8, 10, and 13, as applicable.	<p>Notes: NASA-STD-8719.9 presents distinct requirements for design, analysis and proof load testing depending on the specific classification of the lifting device, as well as the service class or duty cycle; SI developers should contact NASA for guidance if there are questions re: the appropriate classification of the lifting devices or the corresponding requirements. For example, consider a Structural Sling:</p> <ul style="list-style-type: none"> • NASA-STD-8719.9 Sect.10.2.1 Table 10-1 indicates that Structural Slings shall be designed and analyzed to maintain positive margins of safety with a minimum safety factor of 3 against deformation or yielding, and a minimum safety factor of 5 against ultimate failure to support the design load in the vertical/downward direction. • NASA-STD-8719.9 Sect.10.3.1 Table 10-2 indicates Structural Slings shall be proof load tested to 200% of the design load, or 125% of the manufacturer's rated capacity, whichever is higher, for the full length of travel. <p>Rationale: Requirement to ensure SI lifting hardware is load-certified. NASA-STD-8719.9 presents distinct requirements for design, analysis and proof load testing depending on the specific classification of the lifting device, so we have opted to cite this requirements document, and present specific example design / analysis and proof load testing cases based on one (likely) classification.</p> <p>NASA-STD-5005C, <i>Standard for the Design and Fabrication of Ground Support Equipment</i> (Section 4.6.2.1) cites NASA-STD-8719.9, <i>Standard for Lifting Devices and Equipment for lifting devices and equipment</i>. Section 10.2.1, Slings and Rigging, Table 10-1, Structural Slings, specifies these yield and ultimate Safety Factors, which also appear in MSFC-SPEC-1548, <i>GSE Requirements for MSFC STS Experiments</i> (section 3.2.4.1.1).</p> <p>NASA-STD-5005C, <i>Standard for the Design and Fabrication of Ground Support Equipment</i> (Section 4.6.2.1) cites NASA-STD-8719.9, <i>Standard for Lifting Devices and Equipment for lifting devices and equipment</i> (section 10.3.1, Slings and Rigging, Table 10-2, Structural Slings) which specifies these proof load test factors. MSFC-SPEC-1548, <i>GSE Requirements for MSFC STS Experiments</i> (section 3.2.4.1.3) also specifies proof testing for lifting equipment at 2 x maximum working load, with inspections.</p>			Analysis, Test & Inspection	<p>A visual inspection shall be performed after any proof test to confirm no signs of yielding, deformation or other discrepancies (e.g., cracked welds, paint or other surface treatment, surface crazing, loose or missing fasteners, etc.). Test records shall be maintained and available for NASA review.</p> <p>V&V activities to be determined based on specifics of SI GSE designs and applicable sections / paragraphs of NASA-STD-8719.9.</p>	SSP SE&I
3.5.2.6	SI flight hardware to be hoisted at a NASA facility shall be designed to maintain positive Margins of Safety (MS) with a dynamic load factor of 1.5g in both the upward and downward direction.	Dynamic loads due to hoisting (start – stop loads) per MSFC-SPEC-1548, <i>GSE Requirements for MSFC STS Experiments</i> (section 3.2.4.1.2). Because SI flight H/W is designed to higher load factors (e.g., 6g down and 3g up), this requirement is not expected to be a design driver or impact.			Analysis		SSP SE&I
3.5.2.7	SI Ground Support Equipment (GSE) to be hoisted at a NASA facility shall be designed to maintain positive Margins of Safety (MS) with a dynamic load factor of 1.15g in both the upward and downward direction while loaded per the applicable operational scenario.	Dynamic loads due to hoisting (start – stop loads) per MSFC-SPEC-1548, <i>GSE Requirements for MSFC STS Experiments</i> (section 3.2.4.1.2). A lower dynamic load factor of 1.15g (up and down) applies for SI GSE (i.e., SI carts), which are designed and analyzed to maintain positive margins with safety factors of 2 (yield) and 3 (ultimate).			Analysis		SSP SE&I

Paragraph Identification (parid)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parents - SE01-003	V&V Method (multiple selectable)	V&V Activity	V&V Review & Approval Authority
3.5.2.8	SI installation carts shall be designed to ensure that no wheel loses contact with the ground when a load factor of 0.17 or 70 lb-f, whichever is greater, is applied at the highest CG of the combined SI and Cart in any horizontal axis.	<p>GSE cart stability requirement proposed to ensure that the cart will not tip over (to prevent damage the aircraft floor, TA, SI or injury to operator).</p> <p>MIL-STD-1472F, <i>Human Engineering</i> (Table XVIII) and FAA HF-STD-001, <i>Human Factors Design Standard</i> (section 14.5.3, Exhibit 14.5.3.1), referenced by NASA-STD-5005C, <i>Standard for the Design and Fabrication of Ground Support Equipment</i> (section 5.9). For a short time, one person can exert 70 lb-f, so this is considered a lower limit. However, stability should also consider the effects of a sloped surface and even accidents (e.g., where a person trips and falls hard against the cart).</p> <p>The lateral load factor of 0.17 is consistent with a 1:9 slope with a factor of 1.5, which should be sufficient to avoid having to perform tilt table stability testing on the carts, as indicated by DIN EN 1915-2, <i>Aircraft ground support equipment - General requirements</i> - Part 2: Stability and strength requirements, calculations and test methods (includes Amendment A1:2009) (section 7.1).</p>			Analysis	SI teams shall provide mass and center of gravity (CG) information for the Science Instrument only and also mass and CG for the combined Science Instrument and SI Cart, considering all applicable operational scenarios (e.g., cryogen load, full range of cart lift jack, etc.). Stability analysis shall be provided to assure that no wheel will lose contact with the ground with the specified applied load.	SSP SE&I
3.5.2.9	Screws, nuts, bolts or other threaded fasteners that are part of a Science Instrument flight hardware structural load path for design characteristics classified as Critical and are needed to maintain positive Margins of Safety (MS) shall use self-retaining or self-locking features.	<p>Notes: Critical design characteristics defined in SCI-AR-HBK-OP03-2000, Science Instrument Developers' Handbook.</p> <p>Self-locking features such as castellated nuts and cotter keys, lock washers, staking, Loctite, threaded inserts with locking features or safety wiring will satisfy this requirement with no need for further review by the SIAT.</p> <p>In situations where the use of self-retaining or self-locking features is impractical (e.g., where frequent assembly / disassembly is needed, or to assure proper SI function), other approaches, such as the use of torque-striping with inspections, or exceptions may be approved by the SIAT on a case-by-case basis.</p> <p>The use of COTS equipment for SI subsystems is anticipated. While COTS equipment is not exempt from this requirement, in cases where it is deemed impractical to meet this requirement for COTS components, the SI developer must clearly identify this early in the design and airworthiness certification review process for an assessment of risk and possible mitigations (e.g., regular inspections, etc.).</p> <p>Rationale: Requirement to ensure that vibration environment will not cause fasteners that are part of critical structural load paths and are necessary to maintain positive MS to loosen.</p>		3.5.5	Inspection		SIAT

Paragraph Identification (parid)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parents - SE01-003	V&V Method (multiple selectable)	V&V Activity	V&V Review & Approval Authority
3.5.3	Pressure Vessels and Pressurized Systems (PVS)				NVR		
3.5.3.1	SOFIA Science Instrument cryogen reservoirs or dewars (inner vessel) and cryostats (outer shell) shall be designed to withstand the worst-case pressure and inertial loads.	<p>Notes: The structural analysis must consider and incorporate the material properties at cryogenic temperatures, where applicable.</p> <p>These analyses must include: 1. Stress analysis of the inner vessel due to internal pressure loads (considering the evacuated jacket outside this vessel) 2. Stress analysis of the outer shell and window due to the combined effects of external pressure and emergency landing (inertial) loads</p> <p>Refer to ASME Section VIII, Division 2, Parts 4 and 5, for comprehensive guidance re: combination of stresses and analytical methods for pressure vessels.</p> <p>Typically, one or more "drop-off" relief ports or "pop-off" valves are included on the outer shell to safely vent the interior to the cabin environment in the event of a failure of the inner vessel (cryogen reservoir).</p> <p>Analyses must show positive Margins of Safety (MS) and are to be provided to the SIAT for airworthiness review.</p> <p>Rationale: To ensure the integrity of pressurized components for safety and airworthiness certification.</p>		3.5.5	Analysis	<p>The structural analysis must consider and incorporate the material properties at cryogenic temperatures, where applicable.</p> <p>These analyses must include: 1. Stress analysis of the inner vessel due to internal pressure loads (considering the evacuated jacket outside this vessel) 2. Stress analysis of the outer vessel and window due to the combined effects of external pressure and emergency landing (inertial) loads</p> <p>Analyses must show positive Margins of Safety (MS) and are to be provided to the SIAT for airworthiness review.</p>	SIAT
3.5.3.2	Cryogenic Liquid Helium (LHe) reservoirs shall be designed to safely vent the cryogen boil off into the cabin in the event of a sudden loss of vacuum in the insulating jacket.	<p>Notes: Other failure modes, such as the formation of an ice plug of frozen condensate in the fill/vent tubing, window breakage, and o-ring / seal failure must be considered in the design and the submitted analysis report of the cryogenic reservoir and plumbing systems. Typically, redundant flow paths (primary, and secondary or backup) are used for each cryogen reservoir to address and mitigate the risk of ice plug formation in vent tubes and/or on relief ("pop-off") valves or rupture disks.</p> <p>An analysis of the maximum cryostat pressure resulting from a vacuum jacket failure of a liquid Helium reservoir is provided as Appendix C, <i>Liquid Helium Reservoir Relief Tube Neck Sizing Analysis</i> [ref. USRA-DAL-1202-00, <i>Neck Sizing Validation Test Report</i>, June 15, 2004]. The LHe cryogen reservoir neck relief tube(s) must be sized such that the maximum cryogen reservoir pressure P_{max} from this analysis is no more than 25% larger than the Maximum Normal Operating Pressure (MNOP), where $MNOP = 14.7 \text{ psi} + \text{lowest relief valve cracking pressure}$. If P_{max} divided by MNOP is greater than 1.25, additional hydrostatic testing more stringent than that required in paragraphs 3.5.3.3.1 and 3.5.3.3.2 may be required.</p> <p>Analyses are to be provided to the SIAT for airworthiness review.</p> <p>Rationale: To ensure the integrity of pressurized components for safety and airworthiness certification. This requirement ensures that design limit "proof" pressures (i.e., 1.5 x MNOP acceptance test levels) will not be reached or exceeded in the event of a failure of the LHe cryogen dewar vacuum jacket, based on conservative, test verified analysis.</p>	Appendix C	3.5.5	Analysis	<p>Analysis of cryogen reservoir maximum pressure due to failure of dewar vacuum jacket and resulting rapid LHe boil-off.</p> <p>Analysis based on LHe reservoir parameters and demonstrating $P_{max} / MNOP < 1.25$ to be submitted to SIAT for airworthiness review.</p>	SIAT

Paragraph Identification (parid)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parents - SE01-003	V&V Method (multiple selectable)	V&V Activity	V&V Review & Approval Authority
3.5.3.3	Qualification and Acceptance of Pressure Vessels and Pressurized Systems (PVS)				NVR		
3.5.3.3.1	The design of cryogen reservoirs, other pressure vessels and pressurized components of SOFIA Science Instrument shall be shown to be safe through hydrostatic testing to a qualification pressure level defined as MNOP x 2.0	<p>Notes: MNOP = 14.7 psi + lowest relief valve cracking pressure.</p> <p>Cryostat outer housings are not within the scope of this requirement, and need not be tested.</p> <p>In accordance with FAR Title 14 Part 25 para. § 25.1438(c), an analysis may be proposed in lieu of (or in combination with) a hydrostatic qualification pressure test with concurrence of the SIAT that this is equivalent to the required test. In cases where the MS calculated for the inner vessel to demonstrate compliance with para. 3.5.3.1.1 is less than +1.0, this analysis must be a Finite Element Analysis (FEA); Otherwise hand calculations that incorporate stress concentrations associated with welds and geometric discontinuities, non-hemispherical end caps, etc., are generally acceptable to the SIAT. Refer to ASME Section VIII, Division 2, Parts 4 and 5, for comprehensive guidance re: combination of stresses and analytical methods for pressure vessels.</p> <p>This requirement will be satisfied via one of the following two design qualification approaches: 1. Prototype Qualification: The design is qualified via testing to qualification test pressure levels of a single representative non-flight Qualification Model test article, that must be of the same design, materials and fabrication techniques as the Flight Model(s). Subsequent parts or assemblies manufactured / assembled to the same specification using the same materials / components need not undergo additional qualification level hydrostatic pressure testing. For Prototype Qualification, demonstration that the component is able to withstand qualification pressure test levels without catastrophic failure or rupture is sufficient.</p> <p>2. Proto-Flight (PF) Qualification: The ProtoFlight Model (PFM) test article used to qualify the design may undergo established, industry standard Non-Destructive Evaluation (NDE) and be accepted for use in flight hardware if and only if (IFF): a. Comparison of pre- and post-test inspections performed by a certified inspector confirm no formation or propagation of cracks at welds and geometric discontinuities, and; b. Measurements made before, during and after the testing to qualification pressure levels clearly and unambiguously demonstrate that no permanent inelastic (i.e., plastic) deformation or yielding has been sustained. The NDE methods employed to establish that yield has not occurred must have sufficient precision to rule out plausible plastic regime deflections. Refer to ASME Section VIII, Division 2, Part 8, Section 8.2, and Part 7, for a comprehensive discussion of suitable hydrostatic test and NDE inspection procedures, respectively.</p> <p>All pressure tests (non-COTS items) are to be conducted hydrostatically to test procedures that have been reviewed and approved by the SIAT, and must be witnessed by an SIAT representative or designee. The SIAT and SOFIA Science Project personnel are to be notified as soon as a test date is established and at least 3 weeks in advance of the test date. COTS items may be procured with certified vendor documentation demonstrating proof of burst testing and/or analysis by manufacturer. Test reports and analyses are to be provided to the SIAT for airworthiness review.</p> <p>Rationale: To ensure the integrity of pressurized components for safety and airworthiness certification. MNOP x 2.0 is the "burst" or qualification test pressure level specified by FAR Title 14 Part 25 para. § 25.1438(a) for Pressurization Systems</p>		3.5.5	Test and/or Analysis	<p>Hydrostatic pressure test to qualification pressure level defined as MNOP x 2.0.</p> <p>An analysis, or a combination of analysis and test, may be substituted for this qualification pressure test, in cases where the SIAT authority finds this to be equivalent to the required test.</p> <p>Test reports and analyses are to be provided to the SIAT for airworthiness review.</p>	SIAT

Paragraph Identification (parid)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parents - SE01-003	V&V Method (multiple selectable)	V&V Activity	V&V Review & Approval Authority
3.5.3.3.2	Cryogenic reservoirs, other pressure vessels and pressurized components of SOFIA Science Instruments shall undergo proof pressure testing to acceptance pressure levels based on the Maximum Normal Operating Pressure (MNOP) of each component and the applicable factor as defined in Table 3.5-3, <i>Acceptance (Proof) pressure test levels for pressure vessels, lines and components</i> .	<p>Notes: MNOP = 14.7 psi + lowest relief valve cracking pressure.</p> <p>Cryostat outer housings are not within the scope of this requirement, and need not be tested.</p> <p>Proof pressure testing comprises acceptance criteria for pressurized systems to be used in SIs. Such testing is to be conducted once prior to assembly into the SI, and need not be repeated subsequently.</p> <p>Per para. 3.5.3.2, Liquid Helium (LHe) cryogen reservoir neck relief tubes and valves / rupture disks must be sized such that the maximum cryogen reservoir pressure P_{max} result from the analysis presented in Appendix C is no more than 25% larger than the MNOP. If P_{max} divided by MNOP is greater than 1.25, additional and more stringent hydrostatic testing may be required.</p> <p>All pressure tests (non-COTS items) are to be conducted hydrostatically to test procedures that have been reviewed and approved by the SIAT, and must be witnessed by an SIAT representative or designee. The SIAT and SOFIA Science Project personnel are to be notified as soon as a test date is established and at least 3 weeks in advance of the test date. COTS items may be procured with certified vendor documentation demonstrating proof testing by manufacturer.</p> <p>For acceptance, the component or assembly must withstand acceptance pressure test levels without any visible signs of permanent inelastic (i.e., plastic) deformation, yielding or leaks, and a comparison of pre- and post-test inspections performed by a certified inspector must confirm no formation or propagation of cracks at welds and geometric discontinuities.</p> <p>Refer to ASME Section VIII, Division 2, Part 8, Section 8.2, and Part 7, for a comprehensive discussion of suitable hydrostatic test and inspection procedures, respectively.</p> <p>Test reports, COTS documentation, and analyses are to be provided to the SIAT for airworthiness review.</p> <p>Rationale: To ensure the integrity of pressurized components for safety and airworthiness certification. MNOP x 1.5 is the "proof" or acceptance test pressure level specified by FAR Title 14 Part 25 para. § 25.1438(a) for Pressurization Systems.</p>	Table 3.5-3	3.5.5	Test	<p>Hydrostatic pressure test to acceptance pressure levels defined using MNOP and Table 3.5-3.</p> <p>Test reports / COTS documentation are to be provided to the SIAT for airworthiness review.</p>	SIAT

Paragraph Identification (parid)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parents - SE01-003	V&V Method (multiple selectable)	V&V Activity	V&V Review & Approval Authority
3.5.3.4	Pressure systems downstream of pressure regulators shall be designed for either the Maximum Normal Operating Pressure (MNOP) of the pressure source or appropriate pressure relief devices (PRDs) to accommodate a full open regulator failure.	<p>Notes: MNOP = 14.7 psi + lowest relief valve cracking pressure.</p> <p>To support the analysis to show compliance with this requirement, the flow rate through the regulator is to be calculated using the published flow coefficient (Cv) value for the regulator, with calculations in accordance with the procedure provided in Compressed Gas Association (CGA) E-4, <i>Standard for Gas Pressure Regulators</i>, Appendix A.</p> <p>Design and analysis shall anticipate and accommodate any applicable pressure test requirements such that this testing will not be destructive or result in any yield conditions.</p> <p>This requirement is applicable to both ground-based (i.e., GSE) and flight PVS.</p> <p>Rationale: This precludes the possibility of the downstream pressure exceeding the MNOP or placard rating of the lowest rated component. For instance, if the pressure vessel system includes a compressed gas cylinder serviced to 2000 psi supplying pressure to an instrument that is rated to 400 psi, even though the pressure is regulated down to below 400 psi via a pressure regulator, the system must have a pressure relief device set no higher than 400 psi downstream of the pressure regulator.</p>			Analysis & Inspection		SSP SE&I
3.5.3.5	All pressurized systems within SOFIA Science Instrument GSE that are being used at any NASA facility shall comply with NASA-STD-8719.17A, <i>NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PVS)</i> .	<p>Notes: These requirements are applicable to SOFIA SI GSE (e.g., compressed gas cylinders) to be used at DFRC / DAOF facility, and not applicable to flight hardware (e.g., instrument cryostat).</p> <p>The NASA DFRC Pressure Vessels and Pressurized Systems (PVS) Subject Matter Expert and Chief Safety Officers (CSOs) for the SOFIA Science Project (ARC) and SOFIA Aircraft Platform Project (DFRC / DAOF) have highlighted the following paragraphs from NASA-STD-8719.17A which are likely to be applicable to SOFIA SI GSE, and for which formal verification will be expected:</p> <p>¶ 4.4.3.1: New pressure vessels, including heat exchangers, shall be ASME Section VIII code stamped as specified within the scope as being used and registered with the National Board (Requirement). [An example stamp for ASME Section VIII Division 1 pressure vessels is shown as Figure 3.5-1]</p> <p>¶ 4.10.1.11: Pressure safety relief valves shall only be used in accordance with the applicable ASME code of construction (Requirement).</p> <p>¶ 4.10.2.1.2: Safety-related pressure-indicating devices shall meet an appropriate NCS, such as ASME B40.100, UL-404, or MIL-G-18997 (Requirement).</p> <p>Rationale: To ensure the integrity of pressurized GSE components for personnel safety.</p>	Figure 3.5-1		Analysis, Inspection & Test	Formal verification will be expected for the following paragraphs from NASA-STD-8719.17A, and any other paragraphs from this standard that are applicable to SOFIA SI GSE: ¶ 4.4.3.1 ¶ 4.10.1.11 ¶ 4.10.2.1.2	SSP SE&I
3.5.3.6	Flexible hose ends that could subject personnel to a whipping hazard in the event of end connection failure shall be restrained at each end and at least every six feet.	Ensure that pressurized hoses will not become a physical hazard in the event of a hose or end fitting failure.			Inspection		SSP SE&I

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3.5.4	Electrical				NVR		
3.5.4.1	Wiring to Science Instrument design characteristics classified as Critical shall be routed separately from other wiring.	<p>Note: Critical design characteristics defined in SCI-AR-HBK-OP03-2000, Science Instrument Developers' Handbook.</p> <p>Rationale: Protection against common mode failures within Critical SI subsystems required to maintain safety and control.</p>		3.5.5	Analysis & Inspection		SIAT
3.5.4.2	All electrically conductive external surfaces of each item of powered Science Instrument equipment shall be electrically grounded, with a resistance of no greater than 10 mΩ (0.01 ohm) measured between the Science Instrument equipment conductive surface and the applicable local grounding interface location, as defined in Table 3.5-4, <i>Local electrical grounding interface locations for SI equipment</i> .	<p>Notes: The Science Instrument assembly (that portion of the Science Instrument mounted to the Telescope Assembly (TA) Instrument Mounting Flange (IMF) will generally be electrically bonded to the TA via its structural / mechanical interface (unless there are features at that interface specifically designed to isolate these assemblies, in which case a provision to ground the SI assembly via a PI-provided grounding wire or strap will be required in accordance with SOF-DA-ICD-SE03-036 (TA_SI_01), <i>Cable Load Alleviator Device / Science Instrument Cable Interface</i>, paragraphs 4.1.3.3 through 4.1.3.6).</p> <p>SOF-DF-ICD-SE03-048 (TA_MCCS_P), <i>Telescope Assembly / Mission Controls and Communications System (MCCS) Physical Interface</i>, section 3.3.12, Electrical - Bonding and Grounding, provides guidance re: acceptable practices and implementations for meeting these requirements. In particular, section 3.3.12.2, <i>Grounding in Relation to Power Circuits</i>, and the referenced Figure 3.3.12.2-1, <i>Safety (Chassis) Ground Approaches for Consoles, Racks, and Connector Panels</i>, describe various approaches to acceptable grounding of rack-mounted equipment, depending on the specifics of the equipment. Additionally, other subsections within section 3.3.12 provide guidance re: best practices for equipment grounding and bonding and shielding of AC power and signal cables, for Electromagnetic Interference (EMI) reduction considerations.</p> <p>Rationale: Protection of personnel against shock hazards due to electrical faults within SI equipment. Also, keeping all SI equipment referenced to a common, single-point ground (i.e., aircraft structure) is good design practice for EMI/EMC considerations.</p> <p>While 100 mΩ (0.1 ohm) is the typical Class H (Shock and Fault Protection) electrical grounding resistance specification for aerospace applications, Class H specifications are applied end-to-end from equipment to facility / vehicle ground, therefore we have proposed a more stringent (but readily achievable) 10 mΩ (0.01 ohm) specification for the grounding between the SI equipment to the local grounding interface (i.e., the U402 grounding lug, or the conductive PI Rack / CWR structures), to allow for additional resistance in the grounding path between the TA and the aircraft structure via the Cable Load Alleviator (CLA).</p> <p>PI rack(s) and CWR conductive structures will be electrically grounded to aircraft structure with a resistance of no greater than 10 mΩ (0.01 ohm) to nearby grounding provisions via NASA-provided grounding cable assemblies, in accordance with applicable ICD grounding requirements. The referenced ICDs address the verifiable grounding requirement at the applicable interface (i.e., PI Racks to U400/U401, CWR to U402, SI assembly to U402), with the intention that this supports V&V of this specification earlier in the integration flow, before installation on the SOFIA observatory.</p>	Table 3.5-4	3.5.1	Inspection & Test	<p>At PDR, SI developer to present SI equipment grounding plan showing implementation for compliance with this specification.</p> <p>At CDR, SI to present design drawings demonstrating implementation of SI equipment grounding.</p> <p>After build-up of SI to the necessary level of integration (i.e., pre-ship or after SI delivery to DAOF and integration), Inspection of SI equipment and Test to show compliance with this specification.</p>	SSP SE&I

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3.5.4.3	Any ground wire, jumper or strap necessary for Science Instrument equipment compliance with the resistance specification of paragraph 3.5.4.2 shall have a conductor sized to accommodate the maximum current that can be provided by the upstream power interface.	<p>Note: Generally, the use of the same wire conductor size that is specified for the current carrying conductors in the power interface connector and cable is appropriate and recommended.</p> <p>Rationale: Ensures that the grounding provisions have adequate current carrying capacity to accommodate the maximum possible fault current (i.e., a "hard short").</p>		3.5.1	Analysis & Inspection	<p>At PDR, SI developer to present SI equipment grounding plan showing implementation for compliance with this specification.</p> <p>At CDR, SI to present design drawings demonstrating implementation of SI equipment grounding.</p> <p>After SI delivery to DAOF and installation, Inspection of SI equipment to show compliance of as-built configuration with the CDR design.</p>	SSP SE&I
3.8	Logistics				NVR		
3.8.1	Science Instruments with cryostats using expendable cryogens shall meet functional and performance requirements with cryogenic servicing no more frequent than once per 24 hours.	More frequent cryogen replenishment would drive operational costs.			Analysis & Demonstration		SSP SE&I
3.8.2	The design and operations of SOFIA Science Instruments shall permit removal from the SOFIA aircraft within a 10 hour period [TBR 3.8-1].	<p>Notes: This time period includes dummy mass installation and Telescope Assembly re-balancing, and assumes availability of appropriate staffing, readiness of CWR and TA dummy masses, tool kits, work orders, and procedures.</p> <p>As a goal, Science Instruments should permit removal from the SOFIA aircraft within a 6 hour period, to allow this operation to be completed during a single standard work shift.</p> <p>Rationale: Provides basis for multiple science instruments to be used over the life of the program. Also, a flight series may be considered as little as one flight. We need to ensure the ability to swap instruments on deployment as a part of a flight series package. The synergy of SOFIA's instrument suite is an important element of the observatory's expected science return. The time spent changing from one instrument to another can also impact the mission's overall science return.</p> <p>These requirements support the transition between flight series and include those portions of the Science Instrument mounted to the Telescope Assembly IMF, as well as the SI counterweight rack, PI rack and Auxiliary PI rack, where applicable.</p>		3.1.8	Analysis & Demonstration	Prior to CDR, SI developer to provide / confirm timelines for installation and removal of SI from observatory, including cryofill, optical alignment, functional checkout ops., etc.	SSP SE&I
3.8.3	The design and operations of SOFIA Science Instruments shall permit installation on the SOFIA aircraft, optical alignment, cryogenic servicing and cold functional check-out of Science Instruments within a 12 hour period [TBR 3.8-1].	<p>Notes: This time period includes dummy mass removal and Telescope Assembly balancing, and assumes availability of appropriate staffing, readiness of CWR and TA dummy masses, tool kits, work orders, and procedures.</p> <p>As a goal, Science Instruments should permit removal from the SOFIA aircraft within an 8 hour period, to allow this operation to be completed during a single standard work shift.</p> <p>Rationale: Provides basis for multiple science instruments to be used over the life of the program. Also, a flight series may be considered as little as one flight. We need to ensure the ability to swap instruments on deployment as a part of a flight series package. The synergy of SOFIA's instrument suite is an important element of the observatory's expected science return. The time spent changing from one instrument to another can also impact the mission's overall science return.</p> <p>These requirements support the transition between flight series and include those portions of the Science Instrument mounted to the Telescope Assembly IMF, as well as the SI counterweight rack, PI rack and Auxiliary PI rack, where applicable.</p>		3.1.8	Analysis & Demonstration	Prior to CDR, SI developer to provide timelines for installation and removal of SI from observatory, including cryofill, optical alignment, functional checkout ops., etc.	SSP SE&I

Paragraph Identification (parid)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parents - SE01-003	V&V Method (multiple selectable)	V&V Activity	V&V Review & Approval Authority
3.9	Human Factors				NVR		
3.9.1	The design, operations and in-flight access of SOFIA Science Instruments shall be consistent with the following operational constraints and limitations: 1. Access to the SI Forward Side while the telescope is inertially stabilized and tracking (only those portions accessible with the TA Barrier raised). 2. Access to the SI Top, Port and Starboard Sides to the flange while the TA is braked. 3. Access to the Forward Side of the counterweight rack while the TA is braked at a nominal elevation of 20 degrees. 4. Access to the SI Bottom Side while the TA is braked and caged.	<p>Notes: Science Instrument controls and indicators that may require routine access or adjustment during in flight operations should be located in one of the PI racks where possible, and not on those portions of the SI mounted to the TA INF or the CWR.</p> <p>Where such SI controls and indicators must be located in the CWR, note that at elevation angles greater than 20 degrees, some or all of the CWR will likely be inaccessible and/or may have visibility issues.</p> <p>Access to those portions of the SI that are mounted to the TA INF or the CWR which require the TA Barrier to be lowered will require that the TA be braked at a minimum, and also caged where access to the TA itself or the bottom side of the SI are required).</p> <p>Reference SOF-DF-SPE-SE01-003, <i>SOFIA System Specification</i> , Appendix A Figure 1 & Figure 2, <i>SI In-Flight Access</i> .</p> <p>Reference APP-DF-PRO-OP02-2043, <i>Procedure for Crossing the TA Barrier during Flight</i> , for requesting in-flight access to those portions of SI mounted on TA and/or within CWR.</p> <p>Rationale: Access to the science instrument must be provided for minor adjustments/repairs, while in flight, in order to alleviate the need to abort a mission and return to base for a minor problem. However, access must be limited to minimize risks associated with this access. Bent Cassegrain is the type of telescope focus this TA has. What is needed is access to instruments in the pressurized cabin forward of the TA focal point forward of the mounting flange and pressure barrier.</p>		3.1.35	Demonstration		SSP SE&I
3.10	Parts, Materials and Processes				NVR		
3.10.1	Metal Stock Material Certifications				NVR		
3.10.1.1	Any metal material used for the fabrication of Science Instrument Flight Hardware design characteristics classified as Critical, including raw material incorporated into threaded fasteners, shall be accompanied by a Certified Material Test Report (CMTR) to be obtained from the material distributor.	<p>Note: Critical design characteristics defined in SCI-AR-HBK-OP03-2000, <i>Science Instrument Developers' Handbook</i> .</p> <p>Rationale: Required for traceability of materials used in the fabrication of safety-critical components and structures.</p>		3.5.5	Inspection	Inspection of CMTRs for each metal stock material delivery for compliance with criteria established in V&V Compliance field; CMTR records to be maintained	SIAT
3.10.1.2	Any metal material used for the fabrication of Science Instrument GSE design characteristics classified as Critical, including raw material incorporated into threaded fasteners, shall be clearly identified, including heat treatment (or "temper") where applicable, in specifications and drawings.	<p>Notes: For use in GSE hardware, it is generally acceptable to procure metal stock and fasteners from a reputable vendor with source and lot traceability records.</p> <p>The use of Commercial-Off-The-Shelf (COTS) and Modified COTS (MCOTS) hardware is anticipated for Science Instrument GSE. Those portions of GSE that comprise (M)COTS are not exempt from this requirement; all reasonable efforts must be made to obtain material specifications and dimensions to validate the stress analyses and calculated Margins of Safety (MS).</p> <p>Critical design characteristics defined in SCI-AR-HBK-OP03-2000, <i>Science Instrument Developers' Handbook</i> .</p> <p>Rationale: Required for validation of structural analyses and MS results using physical properties and dimensions of materials used in the fabrication of safety-critical components and structures.</p>		3.5.5	Inspection	Inspection of material specifications and dimensions for each metal stock material used in the fabrication and assembly of critical GSE design characteristics. Where material specifications and/or dimensions cannot be obtained (e.g., COTS items), NDE testing may be requested by NASA S&MA in order to validate a low positive MS.	SSP SE&I

Paragraph Identification (parid)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parents - SE01-003	V&V Method (multiple selectable)	V&V Activity	V&V Review & Approval Authority
3.10.2	Electrical Systems				NVR		
3.10.2.1	Cable and Connector Labeling				NVR		
3.10.2.1.1	Each Science Instrument cable shall be labeled at each connector with a unique cable identifier and a unique connector identifier.	Cables that are bundled, routed and restrained are challenging to trace from end to end. In addition, it is important that cables be clearly identified with self-explanatory labels that uniquely identify each cable and where each end is to be connected, so that they can be accurately and unambiguously referenced within procedures that will be executed by Aircraft Operations and Mission Operations staff.			Inspection		SSP SE&I
3.10.2.2	Wire Insulation				NVR		
3.10.2.2.1	Use of wires coated in polyvinylchloride (PVC) insulation or jacketing shall be prohibited.	<p>Note: Reconstruction of PVC components in COTS equipment is recommended if replacement parts that do not use PVC are unavailable, where possible. This is primarily applicable to external cables and connectors. For example, while the power cable for a computer may have a unique connector made of PVC for which a non-PVC replacement is unavailable, the PVC-jacketed and/or insulated cabling between the connectors could be removed and re-fabricated with a Teflon coating.</p> <p>Where reconstruction or replacement of parts that do not use PVC is considered impractical or overly burdensome, the SI developer must clearly identify this early in the design and airworthiness certification review process for assessment of risk and possible airworthy mitigations, possibly including use of shrink tube or other protective sleeving.</p> <p>Rationale: Overheated or burning PVC releases toxic vinyl chloride vapors.</p>		3.5.5	Inspection		SIAT
3.10.2.3	<p>Connectors</p> <p>The following requirement paragraphs 3.10.2.3.1 through 3.10.2.3.3 are applicable for all connectors mounted on aircraft pressure bulkheads:</p>	When the TA gate valve is open, portions of the mounted SI become part of the pressure barrier between the pressurized cabin environment and the ambient stratospheric environment in the telescope cavity. These requirements are necessary to ensure that appropriate measures are implemented to preclude gross leaks through connectors on these portions of the SI from the pressurized cabin.			NVR		
3.10.2.3.1	Connectors shall be sealed to prevent leakage through wiring and contact installations.	<p>Options for meeting this requirement include the use of hermetic connectors, sealing (potting) of the connectors, or by filling unused contact wire entry holes with appropriate unused contact sealing plugs on both the receptacle and plug sides of the mated connector pair.</p> <p>Connectors on pressure bulkheads that are not hermetic, sealed (potted) or closed by using sealing plugs or unused contacts can lead to leaks through the connector shell.</p>		3.5.5	Inspection		SIAT
3.10.2.3.2	Connector receptacles installed on aircraft pressure bulkheads shall be mounted and sealed with the connector flange on the pressurized side of the bulkhead.	Improperly mounted connectors on pressure bulkheads can lead to leaks around the connector shell.		3.5.5	Inspection		SIAT
3.10.2.3.3	A sealing gasket or proper sealing material such as a room temperature vulcanizing (RTV) or aircraft sealant shall be used to prevent pressure leakage at the aircraft bulkhead connector flange.	Improperly mounted connectors on pressure bulkheads can lead to leaks around the connector shell.		3.5.5	Inspection		SIAT

Paragraph Identification (parid)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parents - SE01-003	V&V Method (multiple selectable)	V&V Activity	V&V Review & Approval Authority
3.11	Interface SOFIA Science Instrument interfaces are as depicted in SCI-AR-HBK-OP03-2000, <i>SOFIA Science Instrument Developers' Handbook</i> , Figure [TBD 3.11-1] - <i>SOFIA Science Instrument Interfaces Block Diagram</i> .	This figure provides a very helpful pictorial reference depicting the SOFIA interfaces applicable to Science Instruments, and the corresponding ICDs.		3.11.1	NVR		
3.11.1	SOFIA Science Instruments shall comply with the installation, static, and dynamic envelopes as defined within SOF-DA-ICD-SE03-002 (ICD Global_09), <i>Science Instrument</i>	Note: Science Instruments may be brought aboard the SOFIA aircraft in sections for reassembly once on board.		3.11.1	Analysis & Inspection		SSP SE&I
3.11.2	SOFIA Science Instruments shall comply with the interface requirements of SOF-DA-ICD-SE03-037 (TA_SI_02), <i>Telescope Assembly / Science Instrument Mounting Interface</i> .	Note: TA_SI_02 Figure 4-1 has known inaccuracies and is in revision to correct the locations of the 4 holes with threaded inserts for jack screws [Ref.: Correction to TA_SI_02 Figure 4-1 (09/13-04): Front View of IMF (INF)].		3.11.1			SSP SE&I
3.11.3	SOFIA Science Instruments shall comply with the interface requirements of SOF-DA-ICD-SE03-2015 (SI_AS_01), <i>PI Equipment to PI Rack to Aircraft System</i> .			3.11.1			SSP SE&I
3.11.4	SOFIA Science Instruments shall comply with the interface requirements of SOF-DA-ICD-SE03-036 (TA_SI_01), <i>Cable Load Alleviator Device / Science Instrument Cable Interface</i> .			3.11.1			SSP SE&I
3.11.5	SOFIA Science Instruments that utilize the Counterweight Rack (CWR) on the TA for electronic equipment shall comply with the interface requirements of SOF-DA-ICD-SE03-051 (TA_SI_05), <i>SI Equipment Rack / TA Counterweight Interface</i> .			3.11.1			SSP SE&I
3.11.6	SOFIA Science Instruments that utilize the Counterweight Rack (CWR) on the TA for electronic equipment shall comply with the interface requirements of SCI-AR-ICD-SE03-2027 (SI_CWR_01), <i>SI Equipment to Counterweight Rack</i>			3.11.1			SSP SE&I
3.11.7	SOFIA Science Instruments shall store all imaging and spectroscopic data (for in-flight and post-flight analysis) in Flexible Image Transport System (FITS) format files that adhere to the FITS Standard (v3.0, 10 July 2008) and the SOFIA keyword list as documented within SCI-US-ICD-SE03-2023 (DCS_SI_01), <i>Data Cycle System (DCS) of the SOFIA Project ICD</i> .	Note: Science Instrument data to be stored and transferred to MCCS will include SOFIA subsystem housekeeping parameters as specified within the SOFIA keyword list. Rationale: The FITS standard was developed for the migration of astronomical data across databases and archives. The standard has many incarnations. The SOFIA program must select a FITS compatible format for it's data. Data from all the Airborne Observatory imagers needs to be stored in this format as well as the data from the science instruments. The SOFIA observatory needs to collect housekeeping data from various subsystems and redistribute those data to other subsystems (i.e. TA and SIs) to facilitate the performance of those subsystems during flight and enable the post-flight processing of the science data.		3.1.32 3.1.34	Demonstration		SSP SE&I
3.11.8	SOFIA Science Instruments shall comply with the physical interface requirements for connectivity with the Mission Controls and Communications System (MCCS) as defined within SOF-AR-ICD-SE03-2029 (MCCS_SI_05), <i>PI Patch Panel to PI Equipment Rack(s)</i> .	Notes: Section 3.2.1.1, Power Interface, within this ICD defines the maximum power (KVA for Frequency Converter and UPS supplied AC power and Amps for DC power) available to SI equipment on a per interface connector basis. Additional power available to SOFIA Science Instruments is anticipated for Segment 3 and beyond, and will be reflected in revisions to this ICD.		3.11.1			SSP SE&I
3.11.9	SOFIA Science Instruments that make use of the Telescope Assembly's secondary mirror chopping shall support synchronization with the chopping secondary mechanism via SI-provided synchronization signal or TA-provided synchronization signal as defined within SOF-DA-ICD-SE03-038 (TA_SI_04), <i>TA Chopper Processor / Principal Investigator Computer Direct Analog Interface</i> .	Science instruments that use chopping must be synchronized with the secondary mirror motions. Typically the instrument provides the synchronization signal and therefore an external reference is provided by the instrument. Some instruments can use the internal synchronization signal provided by the TA.		3.1.27	Demonstration		SSP SE&I

Paragraph Identification (parid)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parents - SE01-003	V&V Method (multiple selectable)	V&V Activity	V&V Review & Approval Authority
3.11.10	SOFIA Science Instrument carts and stands to be used within the SOFIA Science and Mission Operations (SSMO) Facility shall comply with the requirements of SCI-AR-ICD-SE03-2017 (SIC_SSMO_01), <i>SI Handling Cart to SSMO Facility Interface</i> .			3.11.1			SSP SE&I
3.11.11	SOFIA Science Instrument carts and stands to be used within the SOFIA aircraft shall comply with the requirements of SOF-AR-ICD-SE03-205 (SIC_AS_01), <i>SI Handling Cart to Aircraft System ICD</i> .			3.11.1			SSP SE&I
3.11.12	SOFIA Science Instruments that utilize the TA Alignment Simulator (TAAS) for optical alignment and checkout shall comply with the interface requirements of SCI-AR-ICD-SE03-2020 (SSMO_SI_02), <i>TA Alignment Simulator (TAAS) to Science Instrument ICD</i> .			3.11.1			SSP SE&I
3.11.13	SOFIA Science Instruments that make use of the SOFIA Vacuum Pump System (VPS) shall comply with the interface requirements of SOF-DA-ICD-SE03-2022 (VPS_SI_01), <i>SI to Aircraft Vacuum Pump</i> .			3.11.1			SSP SE&I

APPENDIX A - Figures & Tables

	Ultimate Load Factors (Gs) for equipment mounted to:	
Direction	Telescope Assembly	Cabin / Airframe
Forward	9.0	9.0
Down	6.0	6.0
Up	3.0	3.0
Lateral	6.0	3.0
Aft	1.5	1.5

Table 3.5-1: Ultimate Load Factors for structural calculations (ref.: paragraph 3.5.2.1)

Load Condition	Primary structure material	Factor of Safety (FS)	Verification Methodology
Ultimate load factor	Metallic or Composite	N/A	Analysis only
Non-inertial limit loads	Metallic	2.250	Analysis only
Non-inertial limit loads	Composite	3.000	Analysis only
Non-inertial limit loads	Metallic or Composite	1.875	Proof load testing to 120% of flight limit loads
Non-inertial limit loads	Metallic or Composite (using well-established composite processes and materials)	1.500	Proof load testing to 100% of design limit load (DLL) in each of the various design cases with no yielding, and when subsequently loaded without failure to 150% DLL using the most critical load case
Note:	An additional joint or fitting Factor of Safety (FS) not less than 1.200 is to be used on all joints and fittings where failure of one fastener, pin, or lug could result in loss of a component or any major portion thereof		

Table 3.5-2: Factor of Safety (ref.: paragraph 3.5.2.1)

PVS Element	Proof Pressure (psi) ^{Note 1}
Vessels	MNOP x 1.5
Lines and Components	MNOP x 2.0 ^{Note 2}
Notes: 1. MNOP = 14.7 psi + lowest relief valve cracking pressure 2. Lines and components need not undergo proof pressure testing as long as a representative test article has successfully undergone pressure testing to qualification pressure test levels (commonly referred to as "burst" pressure testing). With the concurrence of the SIAT, COTS component specifications and Certifications of Conformance may be presented in lieu of proof pressure test results as well.	

Table 3.5-3: Acceptance (Proof) pressure test levels for pressure vessels, lines and components (ref.: paragraph 3.5.3.3.2)

SI Equipment Location	Applicable local grounding Interface Location
SI Assembly	SI assembly grounding lug / test point
CWR	CWR conductive structure
PI Rack(s)	PI Rack conductive structure

Table 3.5-4: Local electrical grounding interface locations for SI equipment (ref.: paragraph 3.5.4.2)

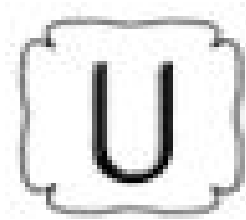


Figure 3.5-1: Example stamp for ASME Section VIII Division 1 pressure vessel (ref.: paragraph 3.5.3.5)

APPENDIX B - Open Issues

Open Issue #	SE01-2028 Paragraph	Action Plan	Actionee	Action ECD
TBR 3.8-1	3.8.2, 3.8.3	Confirm proposed strawman suballocation of 36 hour turnaround time for SI changeout (ref.: SE01-003 para. 3.1.8) to SI being removed (6 hours) and SI being integrated, setup and checked-out for next flight series (8 hours). Confirm 36 hour suballocation to SIs does not include TA balancing and other aircraft platform operations	SOFIA SSP SI Development + Mission Ops	4/4/2011
TBR 3.11-1	3.11	Resolve figure number for SOFIA Science Instrument Interfaces Block Diagram once SOFIA Science Instrument Developers' Handbook, SCI-AR-HBK-OP03-2000, has been developed and formatted.	SOFIA SSP SI Development	4/22/2011

TBD To Be Determined
TBR To Be Reviewed
TBS To Be Supplied

APPENDIX C - Liquid Helium Reservoir Relief Tube Neck Sizing Analysis

The following analysis describes the relationship between the maximum pressure and the neck vent size, based on the known surface area of a helium reservoir and the heat load on the reservoir surface due to the warm ambient air surrounding the reservoir. For single-phase flow, typical of the worst case conditions, the resulting equation is:

$$A = \frac{4\dot{Q}}{5Dv_s(P + P_o)} \quad (1)$$

where A is the neck vent area (m^2), \dot{Q} is the heat load (W), which is the experimentally determined heat flux of 3.7 W/cm^2 multiplied by the total surface area of the helium reservoir in cm^2 , D is discharge coefficient (0.9), $T = 6 \text{ K}$, P is the cryostat internal pressure, and P_o is the ambient pressure (both in Pa, or N/m^2).

After substituting equations which consider the speed of sound in He gas, the ratio of specific heats for He gas ($\gamma = C_p / C_v$), the molecular weight M of He (kg/mol) and the universal gas constant R , the resulting equation is:

$$A = \frac{0.0136 \dot{Q}}{DT^{1/2}(P + P_o)} \quad (2)$$

Equation (2) may be solved for P , assuming that A is known for a specific (or candidate) cryostat and neck vent design.

The additional pressure drop along the neck length due to turbulent flow in the neck can be calculated from the following expression:

$$\Delta P = \frac{1}{2} \psi \frac{lG^2}{\rho d} \quad (3)$$

where G is the mass flow rate per unit area, d and l are the diameter and length of the vent neck, ρ is the density of the He gas (calculated from the ideal gas equation at the neck pressure, mid-way between the internal and ambient pressures, and $T = 6 \text{ K}$), and the Blasius friction factor ψ is:

$$\psi = 0.316 \left(\frac{Gd}{\eta} \right)^{-0.25} \quad (4)$$

where η is the viscosity of the helium gas which is given by $5.18 \times 10^{-6} T^{0.64}$, and once again $T = 6 \text{ K}$. All of the units in equation (3) are in cgs.

Now that P and ΔP have been determined for a given cryostat design using equations (2) and (3) above, respectively, the maximum pressure in the cryostat P_{\max} may be calculated using the following equation:

$$P_{\max} = P + \Delta P \quad (5)$$

Once the maximum reservoir pressure P_{\max} has been determined by this analysis for a specific cryostat and vent neck tube, the SI developer must confirm that $P_{\max} / \text{MNOP} < 1.25$, per paragraphs 3.5.3.2 and 3.5.3.3.2.

The analysis result is to be provided to the Science Instrument Airworthiness Team (SIAT) before the hydrostatic testing is conducted. The hydrostatic test is to be witnessed by an SIAT representative or designee. All pressure tests are to be conducted hydrostatically and must be witnessed by an SIAT representative or designee. The SIAT and SOFIA Science Project personnel are to be notified as soon as a test date is established and at least 3 weeks in advance of the test date. The analysis and report of this test is to be provided to the SIAT for review.